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The Imagery Exploitation System/Balanced Technology Initiative (IES/BTI) is an automated first phase near-real-time image exploitation system to support Army Corps intelligence and electronic warfare situation development, target development and target acquisition. IES/BTI exploits synthetic aperture radar (SAR) and infared (IR) imagery and annotates the presence and type of military units (company size and above).
IES/BTI employs a hierarchial reasoning paradigm, using Bayesian inference for hypotheses management and belief propagation to solve the complex force/terrain/military situation and formation. Evidence gathering actions evaluate the closeness of data supporting the hypotheses to the force models using statistical metrics and/or expert system rules.
IES/BTI has processed data from two military theaters and IES/BTI has learned lessons concerning which methods have worked well and which ideas haven't met expectations. These lessons learned are presented.

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ABSTRACT

The Imagery Exploitation System / Balanced Technology Initiative (IES/BTI) is a first phase near-real time image exploitation system to support Army Corps intelligence and electronic warfare (IEW) situation development, target development and target acquisition. IES/BTI exploits synthetic aperture radar (SAR) and infrared (IR) imagery and annotates the presence and type (artillery, armor, etc) of military units (company size and above).

IES/BTI employs a coarse-to-fine hierarchical reasoning paradigm, using Bayesian inference for hypotheses management and belief propagation to solve the complex force/terrain/military situation image understanding problem. Military forces are modeled at multiple levels of abstraction representing force hierarchy, situation and formation. Evidence gathering actions evaluate the closeness of data supporting the hypotheses to the force models using statistical metrics and/or expert system rules. Some rules are complex dynamically adapting a static force model to the local terrain and threat situation. A uniform certainty calculus defines how evidence from the model match is applied to the hypotheses.

In IES/BTI, hypotheses are stored in the Bayes network a multidimensional hierarchical tree structure where hypotheses and associated evidence are probabilistically linked across dimensions. The state of force hypotheses stored in the Bayes network are monitored by decision theoretic control (DTC) which opportunistically spawns actions to evaluate, refine, spawn and/or prune force hypotheses. IES/BTI completes processing when DTC determines the sufficient evidence has been gathered to answer the exploitation request and image annotations are produced.

In a blind test on 33 images; 2 regiments, 45 battalions and 36 companies of actual enemy forces were identified by IES/BTI.

IMAGERY EXPLOITATION SYSTEM / BALANCED TECHNOLOGY INITIATIVE

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INTRODUCTION

The Imagery Exploitation System / Balanced Technology Initiative (IES/BTI) is a first phase near-real time image exploitation system to support Army Corps Intelligence Electronic Warfare (IEW) situation development, target development and target acquisition. IES/BTI exploits synthetic aperture radar (SAR) and infrared (IR) imagery and annotates the presence and type (artillery, armor, etc) of military units (company size and above).

The IES/BTI Program's historical foundation includes the Advanced Digital Radar Imagery exploitation System (ADRIES) and Model-based Image Sensor Target Exploitation and Recognition (MISTER) programs which provided a technical foundation for automated exploitation of tactical SAR.

IES/BTI is sponsored by the Balanced Technology Initiative with additional support from the U.S. Army Topographic Engineering Center (TEC), Army Space Programs Office (ASPO), Defence Advanced Research Projects Agency (DARPA), Undersecretary of Army for Research and Development (SARDA) and Wright Avionics Laboratory. IES/BTI is being developed by the U.S. Army Topographic Engineering Center (formerly ETL).

MISSION

IES/BTI mission is to provide an automated image exploitation system for situation analysis with a multi-sensor (ASARS, other SAR, IR) capability, provide near-real time processing in an operational (tactical) setting, complete the exploitation task for a ten nautical mile (nm) by ten nm (10 nm X 10 nm) area in less than five minutes (< 5 minutes) with ninety percent (90%) correctness and act as a force multiplier for first phase situation analysis image analysts (IA). Given that IES/BTI will increase the speed and accuracy at which an IA can interpret an image, IES/BTI will increase the volume and image analyst can interpret and therefore provide the Corps commander more knowledge of the battlefield.

Objective

IES/BTI objective is to provide commanders more knowledge of the battlefield by increasing the productivity of softcopy image analysts. IES/BTI will increase the IA's productivity in two dimensions 1) speed and 2) accuracy. IES/BTI increases an IA's speed by relieving the analyst of low-level time consuming tasks and by focusing the analyst on probable forces. IES/BTI increases an IA's accuracy by bringing additional information to the IA's attention and reducing the analysts fatigue factor. IES/BTI is designed to solve the broad area search problem.

Methodology

IES/BTI is designed to automatically perform exploitation before the IA receives the imagery. The analyst is presented the image and results simultaneously. This allows the analyst to focus on the forces present yet allows him to inspect all the imagery and evidence present. In this data flow, IES/BTI technology resides between the image formation process and the analyst work station. See Figure 1.

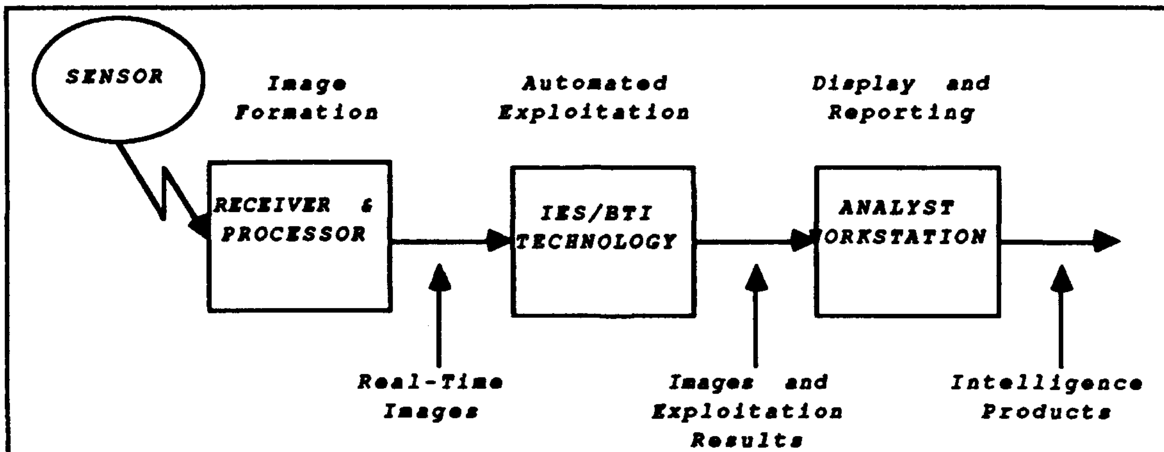

Figure 1. Exploitation Process Data Flow

In this methodology, IES/BTI performs the low-level vehicle detection which currently takes the majority of analysts time. IES/BTI also performs the higher level reasoning of force aggregation, force typing, false hypotheses rejection and merging of various evidence sources and presenting the analyst the results. The analyst can quickly and efficiently focus on the potential forces and evaluate them for accuracy. Via this methodology, the analyst can eliminate major areas of search, concentrate on the most productive imagery and have access to the underlying evidence.

Requirements

Requirements are broken into two sections external and internal. External requirements are driven by published requirements and commanders needs. Internal requirements are driven by external requirements, program goals, good software practices and desires to conform to Army standards and initiatives.

External Requirements

IES/BTI external requirements are derived from the Army Intelligence Master Plan (9/89). Corps IEW timing and location accuracy requirements are given in Table 1 and Table 2. The area within the box indicates the region where imagery is usually used. Currently, tactical electronic intelligence (TacElint) can meet the Corps time requirements but does not support the Corps location accuracy, whereas imagery supports the accuracy requirement.

Table 1. IEW Time Requirements at Corps

	Distance (in km) Beyond FLOT				
Mission	0 - 30	30 - 70	70 - 150	150 - 300	300 +
SIT DEV					
Mover	1.8 min	13 min	13 min	15 min	20 min
Non-mover	15 min	15-60 min	2 hr	3 hr	6 hr
TGT DEV					
Mover	1-2 min	6.5 min	6.5 min	7.5 min	10 min
Non-mover	7.5 min	7.5 min	7.5 min	1.5 hr	3 hr
TGT ACQ					
Mover	2 min	2 min	2 min	N/A	N/A
Non-mover	N/A	N/A	2-3 min*	N/A	N/A

* Prior to attack

Table 2. IEW Location Accuracy Requirements at Corps

Mission	Distance (in km) Beyond FLOT 0 - 30	30 - 70	70 - 150	150 - 300	300 +
SIT DEV	500 m	2 km	3 km	5 km	5 km
TGT DEV	100 m	175 m	350 m	450 m	450 m
TGT AQC	80 m	100 m	150 m	N/A	N/A

Internal Requirements

IES/BTI internal requirements include timing, accuracy, multi-sensor considerations, software standards, compliance with commercial of the shelf policy (COTS), and theater of operation portability requirements. Top level internal requirements are given in Table 3.

Table 3. Top Level IES/BTI Requirements

Requirement
Complete processing of image in less than five minutes
Process in a operational (tactical) setting
Provide multi-sensor capability (ASARS2, other SAR, IR)
Provide 80 m vehicle location accuracy
Provide graceful migration between theaters of operation

Completion of the image within five minutes allows the analyst time (a minimum of 8 minutes for situation analysis) to evaluate the image and IES/BTI analysis before generating his report. This time standard applies to images of one hundred square nautical miles or less (image <= 100 sq nm).

Before program completion, IES/BTI will process in a 20-foot shelter collocated with the Imagery Processing Dissemination System (IPDS) in Europe. IES/BTI may be configured into two standard 19-inch racks for space constrained locations.

IES/BTI will provide an ability to process ASARS2, other SAR and IR. Outputs from JStars and UAV are also under consideration. IES/BTI's intention is to provide the infrastructure and paradigm to allow sensors to be gracefully added as automated vehicle detection when the sensor becomes available.

IES/BTI goal is to provide target acquisition level location accuracy. This accuracy is obtainable when DMA standard products are available for the area of interest (AOI) or when the ephemeris registration provides this accuracy.

The requirement to gracefully migrate between theaters of operation influences the design and modularity of the system. It is IES/BTI intention to keep all adversary and theater information as parameters and data within look-up tables and/or databases.

TECHNICAL PHILOSOPHY

IES/BTI program technical philosophy is to combine three disciplines 1) image and signal processing, 2) knowledge based systems and 3) terrain and military context analysis into one system that emulates the image analysis process. This process uses the coarse-to-fine reasoning of the image analyst to overcome problems associated with the high false alarm/low resolution SAR environment and allows complex reasoning performed in a combinatorially controllable manner. By using similar reasoning strategies and knowledge IES/BTI automatically emulates the image analyst process.

Image Analyst Process

Table 4 outlines the steps in the image analyst process. Within this process, the analyst goes from vehicle level detection to higher level symbolic processing associating vehicles to units and deriving inter-unit relationships. The analyst uses all clues available to him to analyze the image including his prior knowledge of the area, knowledge of effects of situation and terrain on deployment and knowledge of his adversary's tactics. IES/BTI emulation of this process is described in section IES/BTI Processing Paradigm.

Table 4. Steps in the image analyst process

Analyze tasking and plan exploitation strategy
Review Collateral cues (intelligence) Previous coverage Terrain/AOI
Extract evidence from imagery (detects targets)
Group targets into unit components (company/battalion)
Use terrain, other intelligence, military situation as supporting evidence for/against detections and units
Reason about force structure and posture Aggregate units into higher echelon forces Compare force layout against doctrine Predict locations of missing forces/units Integrate terrain information
Generate a report

IES/BTI PROCESSING PARADIGM

The IES/BTI processing paradigm has three characteristic features. First, the paradigm is sensor and theater of operation independent. Second, the paradigm implements the IES/BTI technical philosophy and third, the paradigm emulates the IA process. The IES/BTI processing paradigm is shown in Figure 2.

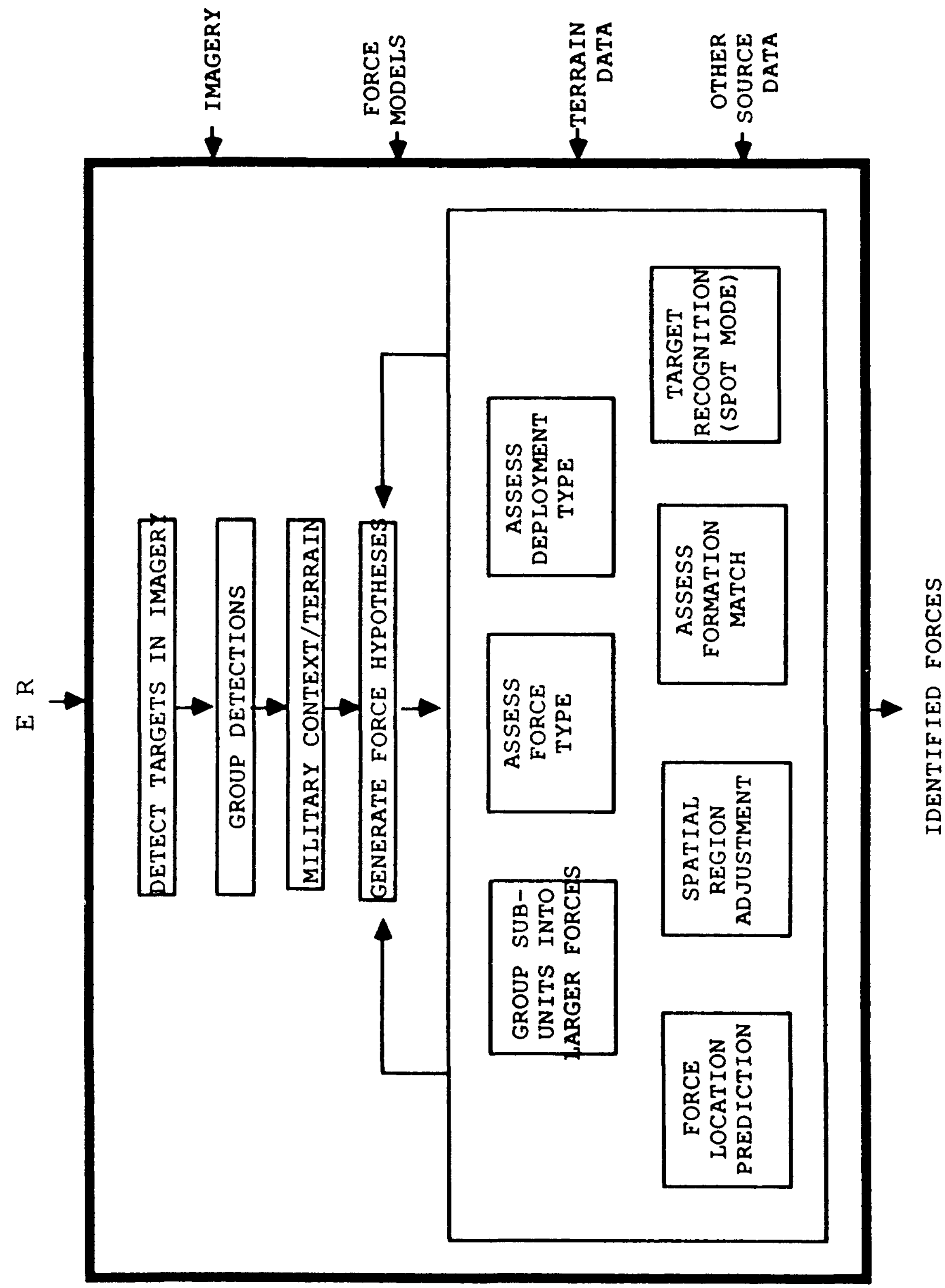

Figure 2. IES/BTI Processing Paradigm

Sensor and Theater of Operation Independence

As shown in Figure 2, IES/BTI is contained within the black box. Everything external to the black box is independent of the IES/BTI processing flow. This means that changing theaters of operation or adversaries in IES/BTI only requires changes in databases, rules and parameters. Therefore software does not need to be changed when changing theaters of operation or adversaries. Similarly, addition of new senors only requires the development of a sensor vehicle detection component and requires the sensors behavior be understood. Sensor dependent information is likewise stored in databases and look-up tables. Control flow which is influenced by both theater of operation and sensor is adjusted by picking the appropriate Directed Acyclic Graph (DAG) for the run. The DAGs define the functionality to be executed.

Implementation of the IES/BTI Processing Philosophy

The implementation of the IES/BTI processing paradigm has five cornerstones 1) model matching, 2) use of multiple evidence sources, 3) coarse-to-fine reasoning, 4) flexible control flow and 5) Bayesian inference.

Models

Models are simply a representation of knowledge. In IES/BTI models occur at every level of abstraction and all evaluation is done by model matching. Examples of models in IES/BTI include statistical characterizations of vehicle detections, artillery deployment patterns, prohibited (no-go) terrain, force composition, force hierarchy and a radar frequency/equipment correlation. Several types of models exist in IES/BTI including statistical analysis, force models, constraint/evaluation models and theoretic control models.

Statistical analysis is the simplest modeling within IES/BTI. Statistical analysis is used when there are known discriminates, exploitable distributions, and non-complex constraints. Statistical analysis is used extensively in Test and Evaluation within the IES/BTI program and in likelihood ratio (LR) calculation. Energy minimization, a related technique is also used in LR calculation. Generally in LR calculations the hypotheses features are compared with distributions of true hypotheses (numerator of LR) and false or null hypotheses (denominator of LR). Vehicle detection LR is an example of the numerator/denominator LR calculation. For detections using current distributions, LRs for military vehicles are greater to or equal to ten (LR >= 10) for ninety percent (90%) of the vehicles, while fifty percent (50%) of false alarms (non-military vehicle detections) have LR of one or less (LR <= 1). Statistical analysis is often used as part of other models in IES/BTI.

Models of forces or force models are hierarchically organized, are multidimensional, serve as the basis for hypotheses within the Bayes network and have characteristic features. Force models have two explicitly hierarchical dimensions force level (echelon) and

type/composition as shown in Figure 3. In IES/BTI, a generic type unit is derived to serve as parent hypotheses for specific (artillery, armor, etc) type unit hypotheses and act as "untyped" unit hypotheses. These generic units have characteristically weaker discriminate value reflected in their features. Forces have implicit dimensions such as military situation and deployment which are treated as features. A list of potential model features is given in Table 5.

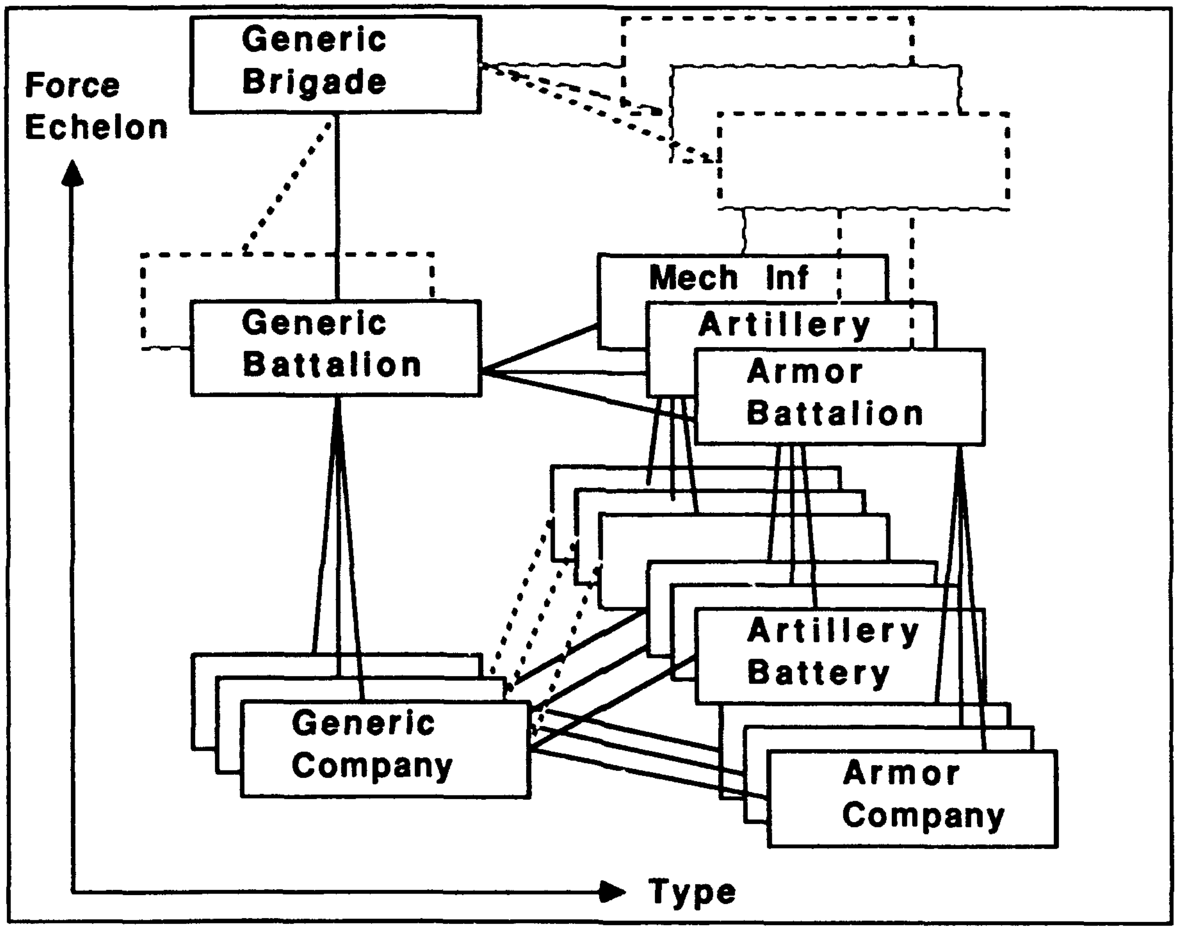

Figure 3. Hierarchy in Force Model Type and Force Echelon.

Table 5. Force Model Features

Force model feature	Feature type
force level	enumeration
type	enumeration
parent unit(s)	list
subunits type/count	distribution
total vehicle count	distribution
deployment	distribution
situation	list
unit width	distribution
unit length	distribution
key(s)	list
constraint(s)	list
pattern(s)	list
density	distribution
uniformity of vehicle LR	distribution
curvature	distribution
linearity	distribution

Constraints and evaluation models can be complex, serve several functions and some are hierarchical in nature. Constraints and evaluation models limit the hypotheses space, provide evidence for or against hypotheses and ultimately influence control flow.

Constraints generally set the context in which a hypothesis will be entertained. For example, units hypothesized to be in "road halt" have presence near a road as a constraint.

Evaluation models are generally the function that maps the evidence via the features or attributes of a hypothesized force to a evidence value (LR). Evaluation models can be simple statistical analysis or a complex combination of constraints, rules, statistical analyses and energy minimization functions. For example, evaluating an artillery battery whose pattern is warped by objective, elevation, treeline and field of fire considerations would take a complex evaluation model. Some of the statistical distributions, rules and energy minimization functions underlying the constraints and evaluation models are sensitive to adversary and theater of operation. Therefore, for optimal performance these data should be verified for each adversary and theater of operation.

Theoretic control models are used to control the computer resources, with the goal of answering the image exploitation request as quickly as possible. The basis of IES/BTI control decision theory is promotion of the highest value actions. Value is a function of action request age, the action's potential payoff and the action's cost.

Use of Multiple Evidence Sources

Using multiple evidence sources provides information not available in the image, provides stronger evidence, and allows more complex (and realistic) reasoning. The three distinct evidence sources used in IES/BTI are imagery, intelligence information and terrain.

Image derived information spawns hypotheses and generally supplies the most evidence for a hypotheses. Image derived information provides most of the metric information about a unit, including vehicle count, inter-unit and intra-unit spatial relationships.

Intelligence information provides situation information and TacElint data. Situation information can provide keys for force models, can drive searches for units and can influence control flow. TacElint can provide keys for force models, can drive searches for targets, provide evidence for forces and influence control flow.

Terrain provides evidence at several levels such as eliminating detections in no-go areas, unit hospitability evaluation, provide constraints and evaluation of force/deployment/terrain interactions.

Interaction between the different evidence sources and the hypotheses features and attributes can be quite complex and the constraint and evaluation models take these interactions into account. Similarly the uniform certainty calculus balances the relative value of evidence from each evidence node within the Bayes network. Use of several evidence sources also limits the number of (reasonable) potential hypotheses by using multi-source constraints.

Coarse-to-fine Reasoning

IES/BTI uses coarse-to-fine hierarchical reasoning to take vehicle detections and form them into the highest echelon, most refined force hypotheses supported by the image analysis. Coarse-to-fine reasoning is hierarchically used to apply constraints at the detection, cluster and force hypotheses levels. Evaluating force hypotheses is inherently a coarse-to-fine process since IES/BTI competes generic and typed force hypotheses. Coarse-to-fine reasoning avoids rejection of true units by allowing generic type units to be gracefully refined into typed units without keeping large numbers of hallucinations (false alarms).

Coarse-to-fine reasoning is implemented in IES/BTI at several levels. Table 6 illustrates the levels of constraints, evidence and reasoning within IES/BTI. The levels of reasoning are detection, cluster, force models and complex force models.

Table 6. Levels of Reasoning within IES/BTI

Level	Reasoning Base
I	Detection
II	Cluster
III	Force model/force hypothesis
IV	Complex force model/force hypothesis

Within the IES/BTI's processing flow shown in Figure 2, the coarsest level of constraints, keys and evidence are applied in a pipeline fashion (the detect, group, military context/terrain portion of Figure 2). Table 7 identifies the constraints and keys placed on data for the pipelined actions in Figure 2. LR indicates a likelihood ratio is computed by the action.

Table 7. Constraints and Keys for Pipelined Actions

Action	LR	Constraints	Keys	Level
Detection	X	size		I
No-go masking		detection not in no-go area		I
Clustering	X	min number of detections		II
		max number of detections		II
		detection density		II
		detection LR >= 10		I
Hospitability	X		near roads	II
TacElint			TE hit	II

As shown in Figure 2, hypotheses are formed and opportunistic generation, search, pruning and evaluation occurs after the pipelined actions. Table 8 shows the reasoning level for opportunistic actions. Group subunits into larger forces, assess force type, assess deployment type and assess formation match represent the next level of coarse-to-fine reasoning. Within these functions force models are matched, as force models are refined in type, situation and deployment constraints and feature distributions are tightened.

Table 8. Levels of Reasoning for Opportunistic Actions

Action	Level	Reasoning Base
Group Subunits	III	Force model/force hypothesis
Assess force type	III	Force model/force hypothesis
Assess formation	III	Force model/force hypothesis
Assess deployment	III	Force model/force hypothesis
Force prediction	IV	Complex force model/force hypothesis
Force SRA	IV	Complex force model/force hypothesis

Finally, spatial region adjustment (SRA) and force location prediction represent the highest levels of coarse-to-fine reasoning. Level IV actions use complex force models/force hypotheses. These complex models often use more than one evidence source (imagery, terrain, TacElint) and often use energy minimization functions to balance conflicting influences. Level IV actions are relatively more costly to perform and their use is limited by the constraints required by the models.

Control Flow

The fourth cornerstone of IES/BTI processing philosophy is a flexible control flow. A flexible control flow allows efficient exploitation of the task and the ability to efficiently process for each theater and adversary. The flexible control flow is supported by Doers and Directed Acyclic Graphs (DAG). Doers and DAGs essentially perform "action planning" and some are dynamic. For flexible control DAGs can be predefined, stored in libraries and called when needed. In this way, the system can be run by several different users each with a different control flow.

Opportunistic control is also part of the flexible control flow. As shown in Figure 2, the first portion of IES/BTI processing is pipelined. However, once hypotheses are formed opportunistic action planning starts. The concept is to allow the state of the hypotheses within the Bayes network to drive further processing by suggesting actions with an associated potential payoff to the Decision Theoretic Controller (DTC) for execution. The DTC uses the age, potential payoff and "cost" to schedule tasks. The process is dynamic as tasks return evidence to the Bayes network and the Bayes Net Manager (BNM) updates the Bayes network's state and then suggests more actions to the DTC. Processing stops when DTC determines sufficient evidence has been gathered to answer the exploitation request and the information is forwarded to the analyst.

Bayesian Inference

Bayesian inference is the method IES/BTI uses to perform higher level inference. Bayesian inference produces a single belief for each hypothesis, correlates evidence with hypotheses within a Bayes network node, correlates evidence between Bayes network nodes and allows estimation of (potential) payoff for actions. The BNM uses Bayesian inference as an integral part of building and updating the Bayes network and for suggesting actions to the DTC. Pearl's algorithm is the basis of implementation within IES/BTI.

Bayesian inference is based upon the theory that given a set of hypotheses H, that are mutually exclusive and exhaustive, subsets of H can have semantic interest and form a hierarchy related through a parent. The effect of evidence on the hypotheses tree or Bayes network can then be defined by a formalism involving estimation, weight distribution and belief updating. Thus Bayesian inference allows evidence to be introduced at any node in the Bayes network and the evidence's effect can be appropriately distributed within the Bayes network.

TEST & EVALUATION

System Test & Evaluation (T&E) is being performed on IES/BTI version 1.5. The testing of version 1.5 is scheduled to be performed in three phases as shown in Table 9.

Table 9. Phases of IES/BTI Test & Evaluation

Phase	Description	Images
1	Tuning	18
1	System Blind Test	33
2	Tuning	51
2	System Blind Test	>60
3	Component Level Analysis	>60
3	Tuning	>111
3	Component Level Analysis	>111

Phase 1 includes a tuning period where developers are allowed to adjust system parameters based on experimentation using 18 images. Phase 1 also includes a blind test on 33 images. None of the blind test images spatially overlap the tuning images.

Phase 2 includes a tuning period where developers are allowed to adjust system parameters based on experimentation using the full set of Phase 1 imagery (51 images). Phase 2 also includes a blind test on over 60 images. None of the Phase 2 blind test images spatially overlap the Phase 1 images.

Phase 3 performs component level evaluation. In Phase 3 results from Phase 2 are evaluated at the component level. Then a system tuning is performed based on the entire set of imagery and component analysis is repeated. Phases 3 serves as a base on which enhancements to version 1.5 can be evaluated.

Image Truth

Image truth serves as the basis of comparison for the T&E effort. Two types of image truth were created "SAR only" and "all source." SAR only is an IA's interpretation based solely on the radar image. All source image truth is based on all the available information with one exception, vehicles were only detected based on the SAR image. This was done to avoid hallucinating vehicles which may have moved. However, all source information could type vehicles (APC, tank, etc) detected in the SAR image.

In creating the image truth, the analysts were not constrained to assigning vehicles to companies, companies to battalions, etc. Analysts could identify elements of units, unassigned vehicles, single companies or whatever they believed the correct interpretation of the data to be.

System Response

System response is IES/BTI's estimate of the forces present in the image. System response attempts to minimize omission errors (misses) and commission errors (false alarm units) and tries to graphically present units in the image to the IA. System response tries to present an uncluttered graphic and tends to be conservative when displaying unit type. Figure 4 is an example of the graphic presentation to the analyst. System response is the IES/BTI's produced basis for system T&E.

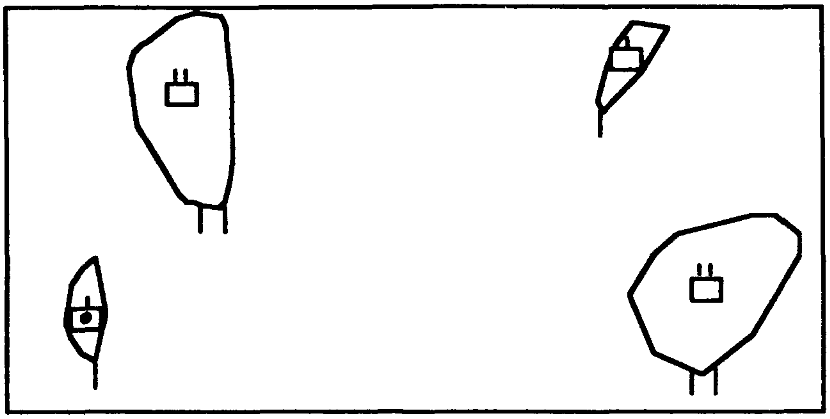

Figure 4. Example of System Response Graphic Overlay.
In this example, 2 untyped battalions, a untyped company and a artillery battery are presented to the analyst.

Tests

Several tests were devised to automatically score the system. The "50 percent test" tests whether system response sufficiently presents units for an analyst to identify it. Under the 50 percent test a "hit" was defined as greater or equal to fifty percent (>=50%) of an image truth unit's vehicles were identified with IES/BTI's system response.

The "null test" tests whether system response totally fails to identify a unit. The null test defined a "miss" as zero (0) of the image truth's vehicles are identified with IES/BTI's system response. A "miss" does not imply the vehicles were not detected, only that any hypotheses containing them were not part of the system response.

The "hallucination test" tests whether system response hypotheses are entirely composed of false vehicle detections and therefore is a system generated hallucination. Hallucinations are defined as hypotheses presented as part of the system results containing

no image truth vehicles. Hypotheses containing "unassigned" image truth vehicles or elements of units are not considered hallucinations.

Results

Phase 1 of the T&E effort is complete and IES/BTI's system response performance against all source image truth are given in Table 11 and Table 12. Table 11, shows how well IES/BTI's system response identified all source units. IES/BTI is designed to find battalion and higher level forces but also identifies companies. Under the 50 percent test, IES/BTI identified both brigades by identifying their sub-forces. For battalions IES/BTI performed significantly worse missing 27 percent of the image truth units and identifying only 61 percent in Phase 1 testing. 12 percent of the battalions had some subunits identified but failed the 50 percent test.

Table 11. Phase 1 Hits & Misses

Unit level	IT	Hits	Partial hits	Misses
Elements	20	14 (70%)	-	6 (30%)
Companies	63	36 (57%)	3 (5%)	24 (38%)
Battalions	74	45 (61%)	9 (12%)	20 (27%)
Brigades	2	2 (100%)	0	0

Table 12 shows how many IES/BTI system response hypotheses were hallucinations. IES/BTI system response did not produce any brigade level hypotheses and therefore produced no brigade hallucinations. 13 percent of the battalion level hypotheses were found to be hallucinations. Note "IES/BTI total" of Table 12 includes partially correct hypotheses such as a company hypotheses composed of image truth "unassigned" vehicles. Also note in Table 11 and Table 12 subunits of a higher force are not included in unit level

Table 12. Phase 1 Commission Errors

Unit level	IES/BTI total	Hallucinations
Companies	138	31 (22subunit)
Battalions	87	11 (13%)
Brigades	0	0

Analysis

Testing is not far enough along to give insightful analysis and totals including subunits is not complete. However, some observations can be made. The image data set included a few null images (containing no units) and system response was restrained in hallucinating units. Missed units and hallucinations were distributed throughout the imagery set indicating a even response across the imagery. At the battalion level, misses were spread across unit type, but at the (independent) company level the majority of missed companies

were support. This may indicate that by adjusting the threshold at which hypotheses are presented as part of system results, performance at the battalion level may be improved. Tuning with a larger data set for Phase 2 testing and using information from Phase 1 testing should improve system response's performance in Phase 2.

REFERENCES

1. J. O. Berger, "Statistical Decision Theory and Bayesian Analysis", Springer-Verlag, New York, (1985).

2. A. Klinger, H. Thomas, B. Haddock, "IES/BTI Concept of Operations (Draft)", IES/BTI Internal Document, (1991).

3. T. S. Levitt, et al, "IES/BTI System Design Document", IES/BTI Minimum Document, (1991).

4. A. M. Mood, F. A. Graybill, D.C. Boes, "Introduction to the Theory of Statistics". McGraw Hill, New York, (1974).

5. J. Pearl, "on Evidential Reasoning in a Hierarchy of Hypotheses", in: Artificial Intelligence, 28:9-15, (1986).